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Quality risks analysis of litchi in supply chain in Guangdong Province in China

Final Thesis

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Abstract

The cold chain improves the quality of litchi logistics, but it brought high technology investment costs to enterprises. Whether to adopt cold chain technology has become a decision-making problem for enterprises. Based on that, a litchi quality experiment was conducted to compare the changes in litchi logistics quality under normal temperature, cold chain, and partial cold chain logistics conditions firstly.

Then, by constructing a two-level supply chain cost-benefit model, the changes in the cost and optimal benefit were analyzed before and after the cold chain technology had been adopted, and obtained the boundary value of the technology investment cost that can increase the supply chain’s revenue. Finally, a calculation example to analyze and verify the theory effectiveness was utilized.

The research found that product quality changes significantly under different logistics conditions. Therefore, wholesale prices, retail prices and order quantities are all affected by product quality and preservation ratio factors. When the adoption cost of cold chain technology was within a certain range, the product price would drop, the order quantity would increase, and the revenue of circulation entities at all levels would increase; when the adoption cost exceeded a certain range, the product price would increase, then the order quantity would decrease, and finally all levels of circulations’ income decreased. In addition, the boundary value of technology investment cost that increases the income of wholesalers, retailers and the overall supply chain is the same. Decision-making basis was provided for litchi operating companies to invest in cold chain technology.

Keywords/tags (subjects)
Litchi, Logistics, Cold-Chain Technology, Cost-Benefit Model.

Miscellaneous (Confidential information)

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Content

1 Introduction

1.1 Basic Condition in Guangzhou

The south part of China mainly includes the Fujian province, Guangdong province, Hainan Province and Yun Nan province, Guangxi province. These provinces have around 0.3 billion population (Fujian: 37 million, Guangdong: 110 million, Guangxi: 46 million…) and most population gather mainly in cities, annual average temperature of the south part of China is around 18 degrees Celsius to 26 degrees Celsius. And the annual average relative humidity is around 70%. Based on these kinds of conditions, the fresh fruits can have a good growth environment. For litchi, where the average annual temperature is above 20 degrees Celsius, the annual precipitation is 1300mm, and the annual sunshine hours are 1,600 hours, the most suitable conditions for planting and growing (Dingli Jia et al., 2011).

However, for fresh products in China, the logistics links in cities in southern China, especially Guangzhou, always suffer from large losses and low circulation efficiency, and they lose 20% -30% annually (Fanruguo et al., 2011). In the context of climate change, the degree of biotic and abiotic stress in warm regions has increased relatively (Rajeev Ranjan al., 2015). Therefore, in Guangzhou, how to reduce the risk of litchi quality affected by temperature and microorganisms is an important supply chain issue.

1.2 Characteristics of litchi growing environment and supply chain in Guangzhou

Litchi is one of the tropical and subtropical fruits with the most stringent requirements on climatic conditions, and the growth environment requirements are different in different periods. In winter, litchi below freezing temperature will be difficult to grow due to freezing damage. Too warm temperature in winter will also prevent flower bud differentiation and result in low yield (Dingli Jia et al., 2011). And

Guangdong Province's precipitation and sunshine time, as well as its geographical location, are suitable for the growth, germination, flowering and pollination of litchi.

However, a geographical environment that is conducive to high yield of litchi like Guangdong is rare in the world. Therefore, the market demand for litchi has also become greater and greater.

The characteristics of lychee's supply chain in Guangzhou are very different from those of ordinary fruits. Because of the perishable nature of litchi, logistics conditions and logistics costs are higher than most fruits, which also lead to unstable supply chains and strong randomness of suppliers (Wenxiao Wei et al., 2012). In addition, litchi can better guarantee the quality when it is well packed and pre-cooled enough or when litchi can be transported with a temperature-controlled express cabinet (Zhu Jiahao et al., 2019).

Therefore, good packaging conditions and good transportation conditions mean good quality assurance, as well as high transportation and labour costs. However, at present, the supply mode of litchi suppliers in Guangzhou is still very primitive, like rickshaw or ordinary truck, and the litchi loss rate is relatively high and the delivery efficiency is relatively low. Guangzhou litchi suppliers have some good economic conditions will also choose to modify some ordinary vehicles to modified cold chain cars. However, the refrigeration conditions and pre-cooling mechanism of most modified cold chain trucks are not up to the standard, which leads to a large number of lychees being refrigerated first and then heated, and the deterioration is worse.

1.3 Quality loss of litchi current situation

Nowadays, in China, the litchi supply chain management have a lot of problems. So, many hard things for the suppliers can be difined. Firstly, the suppliers’ selling scale is too small to get high profits, because the small scale means big market competition which has low efficient and profits as well as the serious waste. China lacks fresh fruits’ core enterprises and large-scale standardized management and transportation

(Zeng Zhi-xong et al., 2019).
After picking up, litchi's storage conditions will limit the supplying lead time. For instance, selling on a large-scale fresh litchi easily result in mass losses. Therefore, during the period of production, transportation and consumption, quality of production and transportation will influence the sustainable development and profit. Cold Chain logistic development can reduce the damage rate of litchi, which guarantees the security and quality of product (Zhu Jiahao et al., 2019). The quality improvement of product could increase the profits rate in supply chain and decrease the losses of manufacturers. However, cold chain requires the high technology and high costs. Precooling conditions and temperature conditions should be controlled by the drivers on the way, hence, manual operation increase the risks of cold chain breaking, which generate the investment efficiency rate reduction.

Therefore, transportation conditions of litchi research will be necessary. However, the level of cold chain logistics of roads and railways in Guangdong is still very low, refrigerated trucks are lacking, and the distribution of cold storage is uneven (mainly in cities, rural transportation is difficult). The development of third-party cold chain logistics is slow and the professional level of employees is limited, resulting in increased time costs, increased transportation costs, and unnecessary waste caused by broken chains (JIANG Nong-hui et al., 2019).

The second problem is that most suppliers have no precooling awareness because of saving cost, which lead the result that most litchi metamorphic fast after customers buying.

The third problem is that suppliers and retailers lack the collaboration consciousness and no regular partnership (Zhu Jiahao et al., 2019), which result that supply chain is not stable and the profits and markets are not stable in China. The next problem is the small sales scope generating that suppliers' bulk selling consciousness are weak and not reliable (LIANG Nai-feng et al., 2019). So, that's why most suppliers still believe the fast selling model to sell litchi. In busy season, maybe the fast selling

model can be available few days, but most time, they still have serious loss. The last problem is that the suppliers lack the brand consciousness and digital competencies, which mean the information asymmetry always happen in the artificial areas.
In China, the research of the litchi's transportation and economic benefit are scarce, especially in Guangdong province. This research chooses the litchi's different transportation conditions to analyse the security of quality and economic benefit, which is the research topic. The prime target is under different conditions' litchi. Research methods are quality tests and cost-benefit model, which will analyse the litchi's supply chain with cold chain transportation and the wholesale price, order quantity, retailing price. Based on these researches, concluding the important boundary value of the decision can provide the reliability of litchi's transportation data.

1.4 Purpose of the Thesis

The rapid development of cold chain logistics is conducive to reducing the damage rate of litchi during the circulation process, ensuring product quality and quality safety to the greatest extend, and improving product quality is also an effective way to increase supply chain profit income and promote farmers' income. However, Because of the relatively high degree of specialization and investment in cold chain logistics, the threshold for companies in various links of the supply chain to enter the cold chain industry is relatively high. Factors such as uncoordinated connection between the various links of the cold chain, asymmetry of information in the supply chain and unreasonable resource sharing mechanism may cause some cold chains to lose their effect, which is known as "broken chains". At the same time, the key operations of temperature control, such as vehicle pre-cooling, cargo loading and unloading, and temperature setting, are all performed by the driver, and the quality of the driver is not uniform. As a result, the actual implementation of the cold chain cannot be carried out, increasing the occurrence of chain disconnection, which makes the overall investment effective. It is necessary to compare and analysing the transportation conditions of litchi.

However, in the field of theoretical research, there are very few studies on the economic benefits of litchi transportation conditions in China. Based on the above problems, this study selects the analysis of litchi quality safety and economics under different logistics conditions as the research theme. The main object is different logistics transportation methods. Under the litchi, the quality experiment, cost-benefit model is used as the research method to analyse the quality, cost and benefits of litchi in the two stages before and after considering the adoption of cold chain transportation technology in the litchi supply chain. The impact of price, order quantity, and retail price decisions has resulted in important boundary values for cold chain adoption decisions for litchi companies, providing a scientific basis for companies to invest in cold chain technology.

Therefore, two important research topics can be defined: 1).Through quality experiments, the changes in the quality of litchi under three logistics conditions are compared (normal temperature, cold chain, broken chain), and provide a scientific basis for the cost-benefit model. 2). Through the cost-benefit model, the impact of cold chain technology adoption on upstream and downstream wholesale prices, retail prices, and order quantity decisions in the supply chain is analysed. From this, it is possible to calculate the important boundary value of the cold chain adoption decision of enterprises at all levels in the litchi supply chain, and provide a decision basis for enterprises to invest in cold chain technology.

Based on the purposes of thesis, two research questions are concluded: 1). What are the different impacts of the three logistics conditions of room temperature, cold chain and broken chain on the quality of litchi? Which logistics conditions have better fresh-keeping effect? 2). Under what circumstances is the company willing to adopt cold chain technology through cost-benefit analysis? In addition, how will factors such as wholesale price, retail price and order quantity affect on the supply chain companies' decision to adopt cold chain technology?

1.5 Research Significance

1), Theoretical significance

The general research of Litchis mainly emphasize the research of frugivorous' quality and the preservation technology. Based on the research of these parts, this article extends the further study of economic effectiveness of litchi's cold-chain supply chain. Analysing the cost of cold chain logistics and litchis' cost-benefits model, the boundary values of retailers' profit situations can be gained. The litchis' supplying companies can make the correct decision of litchis' transportation modes and logistical methods via the boundary values to maximum the profits of retailers and supplement the theoretical significance of litchis' logistic fields in China and in the world.

2), Practical significance

Implementing the cold chain logistics enhance the quality of litchis obviously, which increase the managing cost. Therefore, different litchis' logistic stratums should make the decision based on the benefits and profit situations. Through the production comparisons in various logistical situations, the operators can develop their strategy via analysing and understanding the data changes in supply chain markets and they can have a systematic vision of the situations of managing status and cost-benefits status. After that, operators will be available to make the correction of litchis' using value ensuring to set the appropriate price and increase the profits of operators through analysing the litchis' perishability and long transportation time as well as fresh-keeping ability. Logistics providers also can maximum the using values of litchis via analysing the logistics conditions like normal temperature shipping, cold-chain shipping as well as cold-chain brake shipping. Every member in litchis' logistical chain can cooperate to find out one high efficiency method to increase the litchis' quality and support the development of this industry.

1.6 Research Methods

This thesis is mainly based on the quality testing experiment and mathematical modelling. On the base of quality testing experiment, article focusing on making the further development of economic benefits under the conditions of litchi's supply chain and cold-chain logistics.

The first chapter is background, which define the research object, and explaining the current developing situation as well as the existing problems under the view of supply chain and cold-chain logistics to constructing the research frame and demonstrating the research significances.

The second chapter is literature review, which managed into two different parts. First part mainly includes litchi's quality research pertinent literature which concludes the litchi's biological characteristics and fundamental physiological features of litchis. The second part concludes the economic benefits of litchis' logistics, which mainly involved the current research of cold-chain logistics and point out how this article supplement the existing research result.

The third chapter is about the litchis' quality testing analysis, which demonstrates the experiment purposes and experimental methods as well as tools. Finally contractive analysis of research results will be drawn. In this chapter, comparative experiments are used to test the sample quality of litchi under three different transportation conditions: normal temperature, cold chain, and broken chain. Then the quality of litchi will be analysed by analysing the changes of litchi weight loss rate, fruit hardness change, soluble solids and decay rate. For specific data collection methods, please see the experimental materials and experimental methods section.

The fourth chapter is the cost-benefit model of litchi's cold-chain logistics, which mainly builds the cost-benefit of supply chain under the conditions of taking the cold-chain logistics or not taking the cold-chain logistics. Finally, the 4 different boundary values of taking advices can be gained. First determine the cost range of litchi at the producer and wholesaler to determine the price range of the retailer, and then compare the cost-benefit model of the cold chain with and without the cold chain to determine the cost and benefit of the retailer. The specific cold chain data comes from Chapter 3. From manufacturer to wholesaler, The transportation cost, storage cost, product loss cost, etc. can be determined. From wholesalers to retailers, shipping costs, storage costs, product loss costs, and technology costs can be gained. If a cold chain is used, wholesalers and retailers need to perform a reasonable cost and benefit analysis of the cold chain technology costs they bear, and find the boundary value of the cold chain adoption cost in order to make appropriate decisions.

The fifth chapter is analysis of examples, which inspect the effectiveness of model's boundary values.

The sixth chapter is this article's conclusion, which concludes the results.

2 Literature review

2.1 Litchis’ logistics quality research

China's current cold chain logistics and distribution of fresh fruits have a loss rate of more than 20%, and the incorrect delivery mode and delivery method cause the delivery time to be too long and increase the loss (Zeng Zhi-xong et. al, 2019). Therefore, major companies began to use cold chain technology to support the logistics and transportation of litchi. Studies have shown that current Chinese e-commerce organizations use a simple cold chain logistics model to transport lychees. This mode is a refrigeration method that combines normal temperature transport vehicles, foam boxes, cold storage devices or ice cubes. This mode can achieve basic temperature control, but due to improper lychee re-temperature and pre-cooling mechanism, the loss of lychee is still large (Jiang Nong-hui et. al, 2019). Therefore, this chapter summarizes the importance of reasonable cold chain logistics by analyzing the physiological characteristics of litchi and the factors that affect its storage.

2.1.1 Litchis’ biological characteristics

Litchi is a non-breathing peak type plant. The most suitable breathing environment is oxygen concentration 5% and carbon dioxide concentration 5%. Under this condition, litchi can achieve better fresh-keeping effect. Meanwhile, with proper increase of carbon dioxide concentration and decrease of oxygen concentration, the nutrients of litchi can save more (Dingli Jia et al., 2011). The aging of litchi is a chemical deterioration process. When the litchi matures, the peel produces ethylene, which ripens the fruit and stimulates the activities of polyphenol oxidase (PPO) and peroxidase (POD), causing enzymatic browning and aging of the peel (Rui-fang Tang et al., 2020). When the PH value of anthocyanin is too high (5 ~ 7.5), the peel of litchi will gradually transform to be brown or even black. Therefore, according to the research, controlling the accelerated degradation of anthocyanins after picking litchi can well guarantee the quality of litchi (Zhou Xiao-yuan et al., 2004).

Due to the above limitations, the requirements for litchi planting conditions have also become harsh. According to the summary, the planting conditions of litchi are as follows: 1), Precipitation and temperature: Litchi is easier to grow in a warm and humid climate areas. The annual precipitation of 1300mm to 2500mm at latitudes of 18.3 degrees to 22 degrees is the most suitable area for planting. However, the seasonal distribution of rainfall is also important for litchi. The large rainfall in summer is conducive to the germination and growth of litchi trees, and the low rainfall in winter and spring is conducive to the differentiation of litchi flower buds. The seasonal distribution of precipitation in Guangdong Province satisfies this well (Dingli Jia et al., 2011). 2), An eight-level wind will cause litchi to fall off the branches, or even break the branches, causing damage. Therefore, choosing a suitable litchi planting terrain or establishing a litchi garden windbreak can effectively defend against strong winds (Rajeev Ranjan et al., 2020).

Good planting conditions can guarantee the growth of litchi, and litchi is more likely to deteriorate after harvest. According to the summary of different literatures, the factors of browning and rot of litchi after harvest can be obtained as: 1), Low temperature can inhibit browning, reduce the activity of PPO and POP and the production of ethylene. 2), High humidity can inhibit the water loss of litchi (Zhou Xiao-yuan et al., 2004). 3), Postharvest fruit disease resistance will also decrease and accelerate fruit browning. The reason for the decline in disease resistance is that Adenosine triphosphate (ATP) insufficient cause membrane damage in postharvest processes (Rui-fang Tang et al., 2020). 4), Differences of phenols and antioxidants levels result to the variety of metamorphic speed in postharvest (Rui-fang Tang et al., 2020). However, the reason for this change is the characteristics of the cell membrane, because membrane lipid metabolism affects cell membrane degradation. Membrane phospholipids are hydrolyzed to free fatty acids, which leads to the peroxidation of fatty acids in cell membranes and promotes browning (Mingyang He et al., 2020). 5), Due to the thin and thick skin of litchi, during mechanical harvesting and vehicle transportation, it may cause visible impact damage and may also cause invisible damage to accelerate the water loss or even deterioration of litchi (Weizu Wang et al., 2020).

Physiological value of litchi fruit: 1), Edible value: litchi involves rich sugar, vitamin C, and protein, calcium, phosphorus, iron. 2), Ecological value: litchi is beneficial to maintain water and soil to improve ecology. The nectar and fruits of litchi trees can attract a large number of insects and birds (Chen Yi-yi et al., 2015). 3), Litchi has the value of Chinese medicine and can also be used to prevent some diseases (Mingyang He et al., 2020). Therefore, good preservation technology can ensure that the nutrition of litchi will not be lost and contribute to the medical science.

2.1.2 Litchis' storage influential factors

Litchi matures in the summer climate of high temperature and humidity. Its peel structure is very special which contains two enzymes, polyphenol oxidase (PPO) and peroxidase (POD). In addition, it also contains many phenolic substances (Reichel M et al., 2017). Ripe litchi fruits are prone to browning, rot, physiological disorders and pathogen infections after harvest (Holcroft et al., 2005; Zhang et al., 2015), and will undergo a process of rapid senescence and quality deterioration, manifested as peel browning , dehydration, loss of flavor and susceptibility to pathogen infection (Su et al., 2019). The browning mechanism of lychee peel is very complicated, and there are mainly enzymatic action and non-enzymatic browning reactions.

During the late storage period of litchi, the main enzyme-induced browning reaction is polyphenol oxidase and peroxidase oxidizing phenolic substances (Underhill, Critchley, 1995) and the degradation of anthocyanins (Liu et al., 2007). Therefore, the storage life of lychee under environmental conditions is very short, resulting in a very short shelf life of lychee, which seriously affects the long-distance transportation of lychee and restricts the marketability of lychee products (Jiang et. al, 2003).

Adopting appropriate measures to slow down the quality change of litchi fruit and extending its shelf life is the current research focus (Guo et al., 2020). The low-temperature logistics process "cold chain logistics" based on freezing technology and refrigeration technology improves the fresh-keeping capacity of fresh food and greatly extends the storage period of products. Although low-temperature storage cannot prevent the browning of litchi, it can delay the browning rate of the peel and reduce the browning index to a certain extent, thus slowing down the quality change of litchi.

2.2 The economic effectiveness of litchis' cold-chain logistics

The Litchi's logistics technologies include the packaging, fresh-keeping, transportation, storage and processing as well as the information handling, which are the best channels to enhance the effectiveness of products' logistics. This thesis mainly discuss the cold chain (fresh-keeping), storage costs and transportation costs and calculate the best revenue under various limited conditions.

In 1940, the British scholar John Richard Hicks summarized the opinions of other scholars and established the theoretical basis of cost-benefit research. After that, scholars began to study the cost-benefit in various fields and establish cost-benefit models. Considering that the research in this paper mainly studies the cost-benefit situation of perishables such as litchi, the thesis mainly draws on the prototype of the basic concept and model of cost-benefit in the transaction costs and benefits of the traceable system studied by Banterle A et al., (2008). Then the concept of investment, consumption and income model establishment process of the perishables part in Ma et al., (2004), and the analysis and introduction of perishables transportation cost researched by Jessup et al., (2005) are borrowed to construct the formula restrictions on transportation costs (eg: temperature, humidity, etc.).

Except basic frame construction of system, thesis still needs the boundary value number to make sure the price level and some specific details. Verbic (2006) uses proper price categories to investigate the financial effects of preservation procedures and discusses some key parameters of preservation of perishable products which provide the key parameters in thesis. Emmett J. and Benedict（2008）analyze an expected profit function for a two-period inventory problem and propose a procedure to get an optimal solution which provide the basis of basic boundary value construction. Chun Yang et al., (2010) provide a cost sharing and revenue sharing contract to encourage supply chain to improve the fresh-keeping level for perishable goods which give the concept to share the costs and risks to wholesalers and customers. Ban Ran (2018) show that cost-benefit theory widely helps managers to make the best choice between cost and benefit. With the aim of minimizing the cost of warranty service, Alqahtani and Gupta (2017) design a warranty service cost model to encourage consumers to purchase remanufactured products. Ban Ran (2018) explores the specific impact of cold chain logistics on agricultural products in China through a cost-benefit analysis. From the perspective of economic benefits of closed-loop supply chain, Xiaoping Ma et al., (2020) construct a decision game model considering retailer's fair concerns under different guarantee modes. In summary, the research on agricultural products and cold chain logistics has accumulated a lot of results. Although some studies have begun to introduce the Internet of Things for research, few people have studied the comparison of the cost and benefits of the Internet of Things. And this determines the profit and loss status of the cold chain logistics using the Internet of Things.

3 Litchis' quality testing experiments

3.1 The purpose of experiments

By simulating and comparing three kinds of transportation conditions: normal temperature, full cold chain and key chain break in cold chain, the impact of different logistics conditions on the quality of litchi will be analyzed.

3.2 Methods and Material

The litchi tested was selected from Panyu District, Guangzhou City, Guangdong Province, and the tree was 3 years old. The planting orchard has a long history, good planting conditions, sufficient light and fertile soil, advanced management, and few insect pests. Litchi samples were collected on May 10th, 2019 and sent to the laboratory in batches by refrigerated trucks and normal temperature cars. Refrigerated trucks mainly store samples tested under cold and broken chain conditions, and normal temperature vehicles mainly store samples tested under normal temperature conditions.

The sample size of the three groups of litchi was completely consistent and the texture was uniform. The total sample size was 150 litchis, with 50 samples in each group. The experiment is based on three kinds of transportation conditions, cold chain, normal temperature, broken chain to set up three sets of control experiments. The three groups of litchi are labeled as L1, L2, L3 in numerical order. Among them, the litchi in the two experimental groups of the cold chain and the broken chain must be pre-cooled at the production site, and transported by the cold chain car to the laboratory, and stored in the cold storage. The cold storage manager reduces the temperature of the cold storage to or before the goods enter the cold storage. It is slightly lower than the temperature required for storage of litchi 5 ° C, and the relative humidity of the storehouse is adjusted to a humidity range of 85% to 90% required for storage of fruits and vegetables. The normal temperature experimental group was transported to the laboratory by a normal temperature vehicle and stored at ordinary room temperature. In addition, in order to simulate the situation that the litchi was transported and stored before it was consumed in the market, the litchi in the broken chain group was stored at room temperature for 3 days in the cold storage and then started to measure. The cold chain and normal temperature experimental groups were in the experimental section. Measure the relevant indicators at the beginning of the day. The experiment lasted for 7 days, the indicator detection cycle was 1 day, and 7 * 3 groups of litchi were tested every day.

The quality inspection indicators were weight loss rate, fruit hardness, soluble solids in litchi and rot rate.

The weight loss rate of the fruit was measured by an electronic scale (electronic analytical balance, weighing range: 0-120g, accuracy: 0.0001g). The individual litchi was weighed, and 7 fruits were processed each time, and repeated 3 times. The weight of the fruits before storage The determination of is recorded as the original weight, that is, the weight of each group of fruits before the test, and calculated using the formula:

Fruit weight loss rate = (weight of each group of fruits before the experiment-weight of each group of fruits during the measurement) / weight of each group of fruits before the experiment * 100%

Flesh hardness: Take the flesh of the litchi after measuring the weight, and use a portable fruit hardness tester (range: 0-12kg / cm2 (× 105 Pa), accuracy ± 0.1) to select 3 uniformly spaced points on the equatorial plane , take 3 measurements for each test sample, and take the average value of each group of samples.

Soluble solids were measured with a handheld digital refractometer (measurement range: 0-100%, minimum scale: 0%). The litchi juice solution was sampled three times at a time, and each fruit was measured three times. Take the average value.

3.3 Result and analysis

1), Changes in Weightlessness

In the storage of fruits and vegetables, the skin and fruit surface of the phenomenon of shrinkage and decay is generally in the weight loss rate of more than 5.00%. It can be seen from FIG. 3-1 that the weight loss rate of litchi under normal temperature storage generally shows an upward trend, and gradually increases with the prolonged storage time. At room temperature, the weight loss rate of fruits was up to 4% for 3 days, the skin was wrinkled, the scales and leaves were yellow and dry, the weight loss rate of fruits was up to 9% for 5 days, the fruits were dehydrated and atrocious, the roots and branches were yellowish and dark, and some fruits were covered with yellowish-brown oval spots and even mildew. Under the cold chain, the weight loss rate of litchi showed a slow rising trend, and the weight loss rate of litchi was still not more than 5.00% (3.5%) after 7 days' storage, with no fruit decay and good storage effect. In the case of broken chain, the weight loss rate of litchi from the cold storage to the normal temperature environment and began to measure indicators showed an overall trend of increasing, and the increase range was close to that under normal temperature conditions, and the rise range in 3 days was greater than that under normal temperature conditions, and the weight loss rate reached 5.5%, indicating that the fruit was more likely to rot under broken chain conditions.

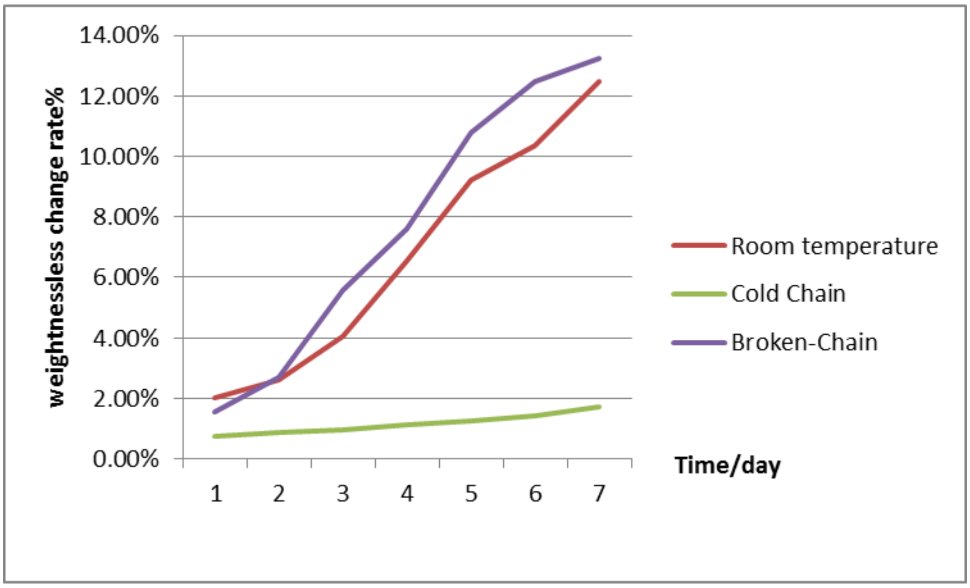


Fig. 3-1: Litchis' weightnessless change rate in experiment.

2), Changes in Fruit Hardness

As shown in FIG. 3-2, the fruit hardness generally shows a decreasing trend at room temperature. Compared with the cold chain condition, the fruit hardness at room temperature is smaller, and the fruit hardness decreases more at room temperature. Under the cold chain condition, the fruit hardness began to decrease slowly on the 3rd day, and rose slightly by 0.005kg/cm2 on the 4th day, and then decreased slowly again, reaching 0.129kg/cm2 on the 6th day. In the case of broken chain, the fruit hardness also showed a decreasing trend, and the decreasing range was close to that of the hardness at normal temperature, until the decreasing range was greater than that at normal temperature on the 5th day, reaching 0.077kg/cm2 on the 6th day.

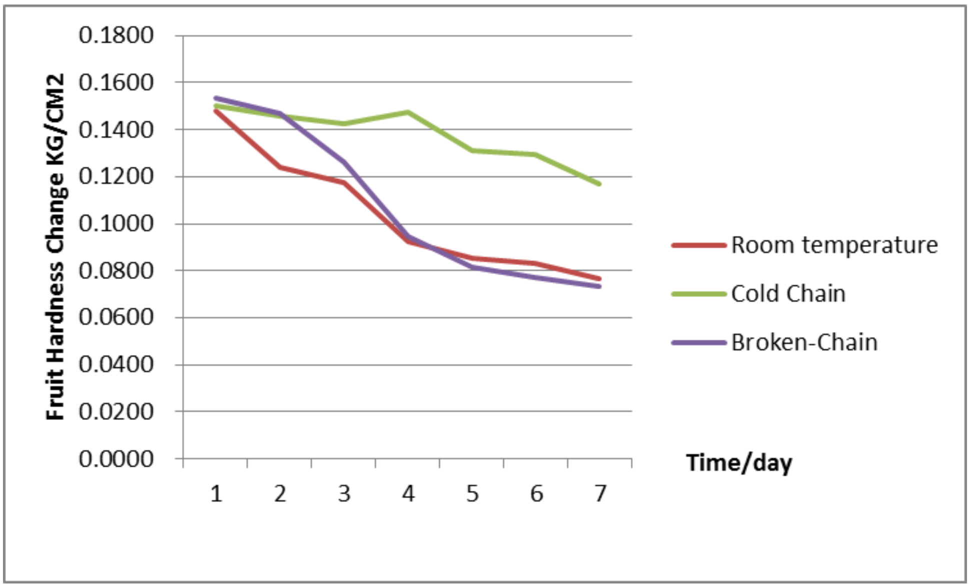


Fig. 3-2: Litchis' hardness change during experiment.

3), Changes of Soluble Solids

The soluble solids content is one of the factors affecting the flavor of lychee fruit. As can be seen from FIG. 3-3, the total soluble solids content of litchi showed a trend of slow increase at room temperature, slightly increased on the third day, and then showed a trend of rapid increase. Lychee was stored at room temperature for 5 days, and the content of soluble solids was the highest during fruit decay, which increased from 13.53% to 16.77% at fruit ripening. Under the cold chain condition, the soluble solids content of lychee increased from 13.92% at harvest time to 15.09% at 7th days after harvest. The change range of soluble hardener in chain breaking parts increased more rapidly than that in normal temperature, from 13.26% on the first day of chain breaking to 17.34% on the fifth day.

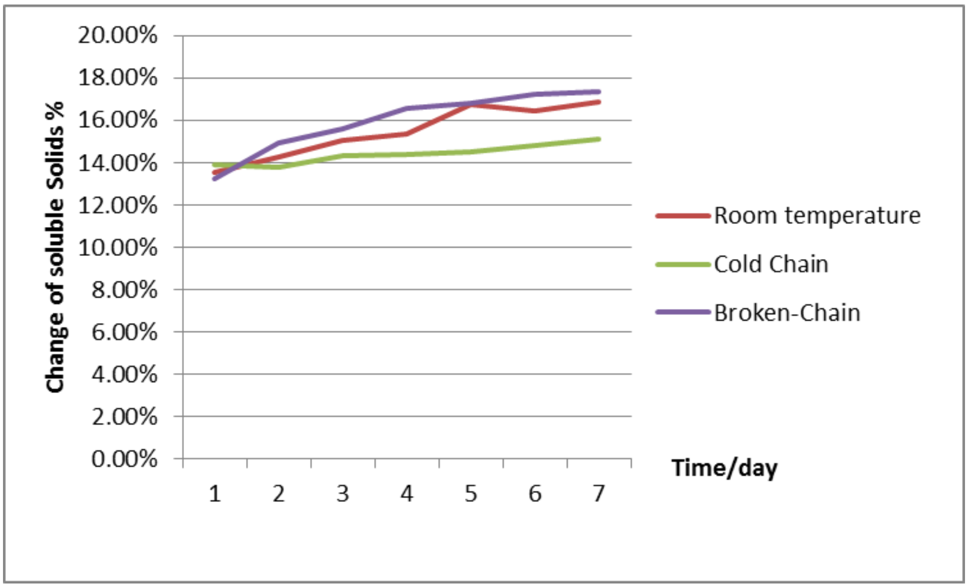


Fig. 3-3: Litchis' soluble solids change during experiment.

4), The conditions of the rate of decay

It can be seen from figure 3-4 that under the cold chain condition, the lychee is well preserved, and no fruit rot occurs within 7 days. In the same period of time, the decay rate of lychee is up to 60.87% after being stored for 5 days at room temperature, and it completely rots on the 7th day. The decay rate increases with the increase of storage time. The decay rate of broken chain parts increased slightly from the beginning, and accelerated on the fourth day, exceeding the normal temperature of the decay rate, up to 73%, in the seventh day all fruit decay.

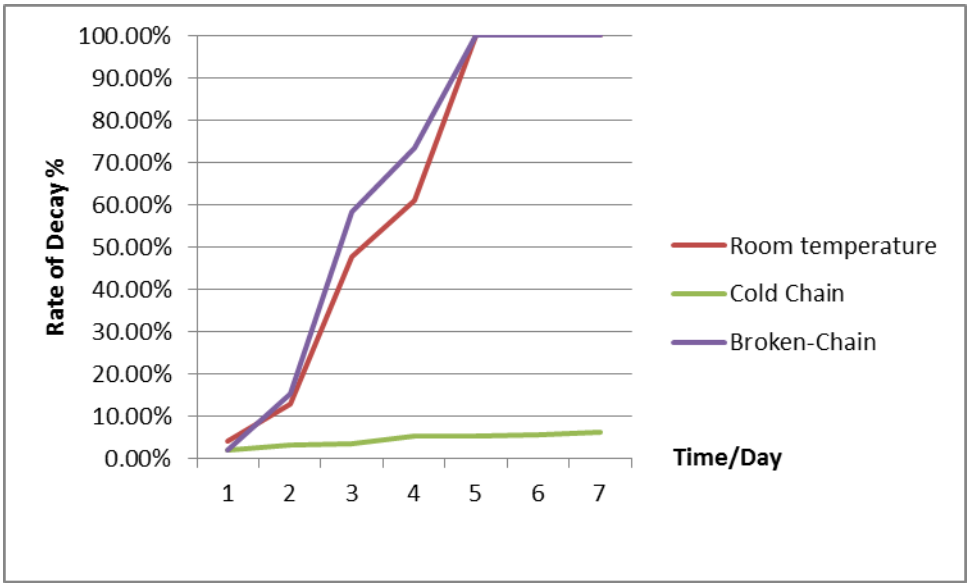


Fig. 3-4: Litchis' decay rate during experiment.

5), Selection of indicators of product quality ratio

During the transportation and storage of products, the quality of the products will decline with time, and a certain loss will occur. The amount of loss depends on the logistics transportation conditions and storage conditions. In addition, litchi decayed slowly when it began to circulate, and the decay rate gradually increased with time. Suppose that the product preservation ratio function ϕ (t) is used to represent the changing law of the quantity of good quality products, and the function takes time t as its independent variable value.

The decay rate is an important indicator for testing the quality of product logistics. Through the comparative analysis of the changes of the above four quality indicators, it was found that the change of the decay rate can better show the preservation status of litchi products and can directly reflect the change of quality. Figure 3-4 shows that with 7 days as the base, litchi completely rots at 5th day and temperatures under normal temperature conditions. The product quality ratio can be referenced to 0.8. Litchi can be stored for 7 days under cold chain conditions. For the sake of rigorous data and reducing errors, the product quality ratio to 0.95 is setted. The analysis of chapter five examples provides data reference.

4 The cost-benefit model of Litchis' cold-chain

4.1 Questions description

This chapter mainly studies the one-way supply process of litchi producer-wholesaler-retailer-consumer and researches the cost of litchi cold chain logistics. In the one-way distribution of litchi, after the wholesaler receives the litchi products delivered by the manufacturer, the optimal wholesale price and order quantity to maximize the profit of its own link are proposed, according to the needs of the retailer, combining the costs and losses in the distribution of litchi products upstream of the supply chain, including transportation cost, storage cost, product loss cost, etc. The retailer determines the appropriate order quantity q based on the wholesale price w, and then considers its own cost based on market demand and product quality. The cost of cold chain logistics at this stage is related to transportation costs, storage costs, product loss costs, and technical costs. To determine the final retail price P.

4.2 Hypothesis

1), Transpotation Cost

Assume that the logistics transportation cost from the place of origin to the wholesaler is borne by the wholesaler, denoted as $\alpha_1(t)$, and the logistics transportation cost of the wholesaler to the retailer is borne by the retailer, denoted as $\alpha_2(t)$. The transportation time is longer, the cold energy consumption will be more, and the transportation cost will be higher. If the time exceeds the limited time, the cost will exceed the budget. If there is a circulation enterprise processing litchi, set the processing cost to L. Assume that the transportation cost function takes time t as an independent variable value, T is a time's limited value, and $0 \le t \le T$, $\partial \alpha_1(t)/\partial_t \ge 0$, $\partial \alpha_2(t)/\partial_t \ge 0$, $\partial^2 \alpha_1(t)/\partial t^2 > 0$, $\partial^2 \alpha_2(t)/\partial t^2 > 0$.

2), Storage Cost

Suppose the storage cost from the place of origin of manufacturers to the wholesalers is borne by the wholesalers, denoted as β_1 (t), and the storage cost from the wholesalers to the retailers is borne by the retailers, denoted as β_2 (t). The storage time is longer, the storage cost is higher. If the time exceeds the limited time, the cost will exceed the budget. Assume that the storage cost function takes time as the independent variable value, T is the limited value time, and $0 \le t \le T$, $\partial \beta_1(t)/\partial t \ge 0$, $\partial \beta_2(t)/\partial t \ge 0$, $\partial^2 \beta_1(t)/\partial t^2 > 0$, $\partial^2 \beta_2(t)/\partial t^2 > 0$.

3), Production Loss Cost

According to the experimental results in the previous chapter, during the transportation and storage of the product, the preservation ratio of the litchi product is higher under the cold chain conditions of lower temperature than the normal temperature conditions. Therefore, it is assumed that the product preservation ratio function $\varphi(e)$ represents the change rule on the ratio of the number of good quality products to the total product quantity, and the function takes the product preservation temperature as its independent variable value. Assuming that the order quantity q provided by the retailer is a fixed value, the wholesale price w set by the wholesaler according to the order quantity is a fixed price. According to the retailer's order quantity q, the wholesaler must deliver $q / \varphi(e)$ products in combination with the prediction of product loss to ensure the quantity of products with good quality. Among them, let Y be the most suitable cold chain temperature for product storage conditions. When e = Y, it means that the product is well preserved. At this time, $\varphi(e) = 1$; when e> Y, it means that the product storage temperature is higher than the most suitable cold chain. Chain storage temperature, at this time, some products appear to be damaged or even completely damaged, reaching $\varphi(e) = 0$. Therefore, the function characteristics are as follows: $0 \le \varphi(e) \le 1$, $\partial \varphi(e)/\partial e < 0$, $e \ge Y$.

Suppose that the product quality function $\gamma(e)$ represents the law of litchi quality change with temperature changing, and the function takes temperature as its independent variable value. From the results of the experimental chapters in this article, it can be concluded that the quality of litchi products is better under cold chain conditions at lower temperatures than normal temperature conditions. Y is the most suitable cold chain temperature for product storage conditions is set. When e = Y, it means the best product quality, at this time $\gamma(e) = 1$; when e> Y, it means that the product storage temperature is higher than the most suitable cold chain temperature Chain storage temperature, at this time the product quality will decline, or even completely damaged, reaching $\gamma(e) = 0$. Therefore, the function characteristics are as follows: $0 \leq \gamma(e) \leq 1$， $\partial \gamma(e)/\partial e < 0$， $e \geq Y$.

4), Cold-Chain Technology Cost

Suppose that the cold chain adoption cost C_z is composed of the fixed cost C_f of technical hardware expenses and the variable cost C_v of application technology, that is, $C_z=C_f+C_v$. The adoption of cold chain technology can improve product quality, reduce product loss rate and extend the shelf life of litchi, high value to obtain higher profits. The adoption of cold chain technology is mainly in the wholesale and retail links of the circulation process. It is assumed that wholesalers and retailers jointly bear the cost of adoption. This is reflected in the fact that wholesalers increase the cost of adopting cold chain technology, and then transfer part of the cost of adoption to retailers by raising the wholesale price.

5), Product Cost and Market Demand Function

Assuming that the cost of litchi origin manufacturers is C_0, for the convenience of calculation, the residual value at the end of the season is set to zero.

Market demand is mainly affected by retail prices and the quality of litchi products. Under the same product quality, the retail price is higher, the market demand is smaller. Under the same retail price conditions, the product quality is better, the market demand is greater. $D=Ap-k\gamma(e)$ represents the market demand function, where k（$k>1$） is the price elasticity coefficient and A is the market size coefficient.

6), Cost Function and Profit Function

Suppose that Cxy represents the cost function, and πxy represents the profit function, where $y \in \{sc,m,r\}$ represents the whole litchi supply chain, wholesalers and retailers, respectively, and $x \in \{N,G\}$ represents the cold chain technology and two cases of adopting cold chain technology.

The wholesaler's cost is composed of transportation cost, storage cost and product loss cost; the retailer's cost is composed of transportation cost, storage cost, processing cost and purchase cost. Since both wholesalers and retailers have to bear their own transportation and storage costs, if cold chain technology is adopted, in theory, both parties should jointly bear certain technical costs.

4.3 Modeling and Solving

4.3.1 Litchis' cost-benefit model without cold-chain supporting

① Retailer's cost-benefit model

From the perspectives of cost-benefit (Emmett J et al., 2008) (BAN Ran, 2018) (Zhaofu Hong, 2019), when cold chain technology is not adopted, the costs and benefits of retailers in the litchi supply chain should be:

$$C_N^r = q_N(w_N + \alpha_2(t) + \beta_2(t) + L) \qquad (4\text{-}1)$$

$$\pi_N^r(p_N, q_N) = q_N(p_N - w_N - \alpha_2(t) - \beta_2(t) - L) \qquad (4\text{-}2)$$

Use e_1 to indicate the product transportation and storage temperature without adopting cold chain technology. According to the market demand function: $D=Ap^{-k}\gamma(e_1)$. $p_N = (\frac{A\gamma(e_1)}{q_N})^{\frac{1}{k}}$. can be got. Substitute into (4-2):

$$\pi_N^r(p_N, q_N) = q_N((\frac{A\gamma(e_1)}{q_N})^{\frac{1}{k}} - w_N - \alpha_2(t) - \beta_2(t) - L) \qquad (4\text{-}3)$$

Calculating the second derivative of q_N, the second derivative is less than 0. So the first derivative is 0 to get the maximum profit, the order quantity when there is an optimal decision:

$$q_N^r = A\gamma(e_1)(\frac{k-1}{k(w_N+\alpha_2(t)+\beta_2(t)+L)})^k \qquad (4\text{-}4)$$

The cost and benefit of substituting the optimal decision of the retailer are:

$$C_N^r = A\gamma(e_1)(\frac{k-1}{k})^k(w_N + \alpha_2(t) + \beta_2(t) + L)^{1-k} \quad (4\text{-}5)$$

$$\pi_N^r = A\gamma(e_1)\left(\frac{k-1}{k}\right)^k(w_N + \alpha_2(t) + \beta_2(t) + L)^{1-k}(\frac{1}{k-1}) \quad (4\text{-}6)$$

② Wholesalers' Costs and Benefits

When the retailer's order quantity is q_N, for the wholesaler, due to the loss in the circulation process, the actual loss of litchi products can be considered through the product preservation ratio function $\varphi(e_1)$, and the wholesalers must provide $q_N/\phi(e_1)$ products. Therefore, the effective value of the ordered product can be guaranteed. The costs and benefits of wholesalers can be expressed as:

$$C_N^m = \frac{q_N}{\varphi(e_1)}(\alpha_1(t) + \beta_1(t) + C_0) \quad (4\text{-}7)$$

$$\pi_N^m(w_N) = w_N q_N - \frac{q_N}{\varphi(e_1)}(\alpha_1(t) + \beta_1(t) + C_0) \quad (4\text{-}8)$$

Calculate the derivation of W_N, set the first derivative is 0, and the best wholesale price for wholesalers is:

$$w_N^* = \frac{\alpha_2(t)+\beta_2(t)+L+\frac{k(\alpha_1(t)+\beta_1(t)+C_0)}{\varphi(e_1)}}{k-1} \quad (4\text{-}9)$$

Through (4-9), it is found that the wholesale price is affected by transportation cost, storage cost, products quality and preservation ratio.

In order to show the influence of wholesale prices on various parameters in the overall supply chain of litchi, substituting the wholesale price formula into the order quantity formula, retail price formula, retailer cost formula, and retailer revenue formula, can get:

$$q_N^{r*} = A\gamma(e_1)(\frac{k-1}{k})^{2k}(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{-k} \quad (4\text{-}10)$$

$$p_N^{r*} = (\frac{k}{k-1})^2(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)}) \quad (4\text{-}11)$$

$$C_N^{r*} = A\gamma(e_1)(\frac{k-1}{k})^{2k-1}(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{1-k} \quad (4\text{-}12)$$

$$\pi_N^{r*} = A\gamma(e_1)\left(\frac{k-1}{k}\right)^{2k-1}(\frac{1}{k-1})(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{1-k} \quad (4\text{-}13)$$

Substituting the optimal order quantity and the optimal wholesale price into the wholesaler's cost and benefit formula:

$$C_N^{m*} = A\gamma(e_1)(\frac{k-1}{k})^{2k}(\frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{-k} \quad (4\text{-}14)$$

$$\pi_N^{m*} = A\gamma(e_1)(\frac{k-1}{k})^{2k}(\frac{1}{k-1})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{1-k} \quad (4\text{-}15)$$

③ Overall supply chain costs and benefits

In summary, the total cost of supply chain circulation without adopting cold chain technology is:

$$C_N^{sc*} = A\gamma(e_1)\left(\frac{k-1}{k}\right)^{2k-1}(\alpha_2(t)+\beta_2(t)+L+\frac{(2k-1)(\alpha_1(t)+\beta_1(t)+C_0)}{k\varphi(e_1)})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{-k} \quad (4\text{-}16)$$

$$\pi_N^{sc*} = A\gamma(e_1)\left(\frac{k-1}{k}\right)^{2k-1}(\frac{2k-1}{k(k-1)})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0}{\varphi(e_1)})^{1-k} \quad (4\text{-}17)$$

Through the above formula, it can be concluded that the wholesale price and retail price are affected by transportation costs, storage costs, product quality and preservation ratio, and the order quantity is also affected by the market size coefficient.

4.3.2 Litchis' cost-benefit model with cold-chain supporting

According to the quality experiment data, the adoption of cold chain logistics technology in the litchi supply chain can significantly improve the quality of litchi products and effectively reduce the loss rate of products. Therefore, wholesalers can reduce the supply quantity of litchi products and reduce costs, thus affecting wholesale prices. Furthermore, the retailer adjusts the retail price and order quantity of the product according to the product quality and wholesale price, and obtains greater profits.

Assuming that the circulation time after adopting the cold chain technology remains unchanged, it is still t, so the transportation cost and storage cost remain unchanged.

Since the storage temperature of the product drops from e_1 to the cold chain temperature e_2 that is more suitable for storage, the product storage ratio and product quality are improved, and its function satisfies $0 \leqslant \phi(e_1) < \phi(e_2) \leqslant 1$, $0 \leqslant \gamma(e_1) < \gamma(e_2) \leqslant 1$. From the perspectives of cost-benefit (Emmett J et al., 2008) (BAN Ran, 2018) (Zhaofu Hong, 2019), the formula can be concluded above.

The wholesale price after adopting the technology is:

$$w_G^* = \frac{\alpha_2(t)+\beta_2(t)+L+\frac{k(\alpha_1(t)+\beta_1(t)+C_0+C_Z)}{\varphi(e_2)}}{k-1} \quad \text{(4-18)}$$

Retailer retail prices and optimal order quantities are:

$$q_G^{r*} = A\gamma(e_2)(\frac{k-1}{k})^{2k}(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{-k} \quad \text{(4-19)}$$

$$p_G^{r*} = (\frac{k}{k-1})^2(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)}) \quad \text{(4-20)}$$

1) Wholesalers' costs and benefits

   From the above formulas 4-18, 4-19, and 4-20, the minimum cost and maximum benefit expressions of wholesalers are:

$$C_G^{m*} = A\gamma(e_2)(\frac{k-1}{k})^{2k}(\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_1)})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{-k} \quad \text{(4-21)}$$

$$\pi_G^{m*} = A\gamma(e_2)(\frac{k-1}{k})^{2k}(\frac{1}{k-1})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{1-k} \quad \text{(4-22)}$$

2) Retailer's costs and benefits

   The minimum cost and maximum profit expressions of retailers available from the above formulas 4-18, 4-19, 4-20 are:

$$C_G^{r*} = A\gamma(e_2)(\frac{k-1}{k})^{2k-1}(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{1-k} \quad \text{(4-23)}$$

$$\pi_G^{r*} = A\gamma(e_2)\left(\frac{k-1}{k}\right)^{2k-1}(\frac{1}{k-1})(\alpha_2(t)+\beta_2(t)+L+\frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{1-k} \quad \text{(4-24)}$$

3) Overall supply chain costs and benefits

   From the above formulas 4-21, 4-22, 4-23 and 4-24 supply chain total cost and total benefit expression is:

$$C_G^{SC*} = A\gamma(e_2)\left(\frac{k-1}{k}\right)^{2k-1}(\alpha_2(t) + \beta_2(t) + L + \frac{(2k-1)(\alpha_1(t)+\beta_1(t)+C_0+C_Z)}{k\varphi(e_2)})(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{-k} \quad (4\text{-}25)$$

$$\pi_G^{SC*} = A\gamma(e_2)\left(\frac{k-1}{k}\right)^{2k-1}(\frac{2k-1}{k(k-1)})(\alpha_2(t) + \beta_2(t) + L + \frac{\alpha_1(t)+\beta_1(t)+C_0+C_Z}{\varphi(e_2)})^{1-k} \quad (4\text{-}26)$$

Through the above formulas 4-25 and 4-26, it can be concluded that after the adoption of cold chain technology, both wholesale and retail prices are affected by the cost of cold chain adoption. The income of circulation entities at various levels and the overall income of the supply chain vary due to changes in transportation and storage costs, cold chain adoption costs, product quality, and preservation ratio. Among them, the income of circulation entities at all levels and the overall supply chain revenue are mainly different from the market price elasticity coefficient.

4.3.3 Boundary values' confirmation

For wholesalers and retailers, the wholesale price, retail price, and order quantity in the circulation process of the litchi supply chain will be affected by all aspects. After applying the cold chain technology, the income of the circulation entities at all levels should be no less than the profit before applying the cold chain technology, but at the same time the total cost after the application of the technology will also increase. Therefore, wholesalers and retailers need to conduct a reasonable cost and benefit analysis of the cold chain technology costs they bear, so that to find the boundary value of the cold chain adoption cost and make appropriate decisions.

(1) Determination of the overall supply chain's profit margin

After adopting the technology, the formula $\pi_G^{SC*} \geq \pi_N^{SC*}$ can be got when the total revenue of the supply chain increases. Based on the above formula, then it convert to $C_z \leq [\gamma(e_1)/\gamma(e_2)]^{1/(1-k)} * \{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\varphi(e_1)\} * \varphi(e_2) - [\alpha_2(t)+\beta_2(t)+L] * \varphi(e_2) - [\alpha_1(t)+\beta_1(t)+C_0]$. Let C_Z^{sc} be the expression on the right side of the inequality. Since $0 \leq \phi(e_1) < \phi(e_2) \leq 1$, $0 \leq \gamma(e_1) < \gamma(e_2) \leq 1$, and $k > 1$, $C_Z^{sc} > 0$. Therefore, C_Z^{sc} is the decision boundary value of whether the total return of the litchi overall supply chain in the two stages before and after technology adoption.

Corollary 1: After technology adoption, when $0 \leqslant C_z \leqslant C_Z^{sc}$, the total revenue of the litchi supply chain increases. When $C_z > C_Z^{sc}$, the total revenue of the supply chain decreases. Among them, C_z is the cost of technology adoption, and C_Z^{sc} is the overall profit margin of the supply chain.

$$C_Z^{sc}=[\gamma(e_1)/\gamma(e_2)]^{1/(1-k)}*\{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\varphi(e_1)\}*\varphi(e_2)-[\alpha_2(t)+\beta_2(t)+L]*\varphi(e_2)-[\alpha_1(t)+\beta_1(t)+C_0] \quad (4\text{-}27)$$

(2) Determination of profit margins between wholesalers and retailers

When the income of wholesalers and retailers increases, the formula can be obtained: $\pi_G^{m*} \geq \pi_N^{m*}$, $\pi_G^{r*} \geq \pi_N^{r*}$. It can be derived from two inequalities, $C_z \leq [\gamma(e_1)/\gamma(e_2)]^{1/1-k}*\{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\varphi(e_1)\}*\varphi(e_2)-[\alpha_2(t)+\beta_2(t)+L]*\varphi(e_2)-[\alpha_1(t)+\beta_1(t)+C_0]$. The formula on the right side of the inequality is same as the overall profit boundary value of the supply chain C_Z^{sc}. Therefore, it can be considered that when $0 \leq C_z \leq C_Z^{sc}$ after technology adoption, the profits of both wholesalers and retailers increase, and their profits boundary value is the same, and is consistent with the overall profit boundary value of the supply chain; when $C_z > C_Z^{sc}$, the revenue of wholesalers and retailers decreases, and the total revenue of the supply chain decreases.

Corollary 2: After the technology is adopted, both the wholesaler and the retailer's revenue increase. Their profit margins are the same and consistent with the overall profit margins of the supply chain.

(3) Determine the boundary value of whether the wholesale price increases

If the wholesaler's price rises in the two stages before and after technology adopting, the formula: $w_G^* \geq w_N^*$ can be drew. Therefore, $C_z \geq (\alpha_1(t)+\beta_1(t)+C_0)(\varphi(e_2)/\varphi(e_1)-1)$. Let C_Z^w be the expression on the right side of the inequality. Obviously, $C_Z^w > 0$. Therefore, C_Z^w is the decision boundary value of whether wholesalers raise prices in the two stages before and after technology adopting.

Corollary 3: After the adoption of the cold chain technology, the wholesaler will reduce the wholesale price due to the reduction of product loss costs. Therefore, wholesalers can obtain more orders to achieve the purpose of small profits but quick turnover. When the cost of technology adoption is too high, wholesalers will raise the wholesale price, transfer part of the cost of adoption to retailers to bear, or refuse to adopt technology. When $0 \le C_z \le C_z^w$, the wholesaler reduces the wholesale price. When $C_z > C_z^w$, the wholesaler raises the wholesale price. Based on these conditions, the formula can be gained:

$$C_z^w = (\alpha_1(t) + \beta_1(t) + C_0)(\frac{\varphi(e_2)}{\varphi(e_1)} - 1) \qquad (4\text{-}28)$$

(4) Determine the boundary value of whether the retail price increases

If the retailer raises the retail price in the two stages before and after the adoption of cold chain technology, there is $p_G^* \ge p_N^*$, then $C_z \ge (\alpha_1(t)+\beta_1(t)+C_0)(\varphi(e_2)/\varphi(e_1)-1)$. The expression on the right side of the inequality is the same as the boundary value of whether the wholesale price increases C_z^w, so C_z^w is also used as the decision boundary value of whether the retailer increases retail price in the two stages before and after cold-chain technology adopting.

Corollary 4: After the adoption of the cold chain technology, the retailer will reduce the retailing price due to the reduction of product loss costs. Therefore, retailers can obtain more orders to achieve the purpose of small profits but quick turnover. When the cost of technology adoption is too high, retailer will raise the retailing price, transfer part of the cost of adoption to customers to bear, or refuse to adopt technology. When $0 \le C_z \le C_z^w$, the retailers reduce the retailing price. When $C_z > C_z^w$, the retailer raises the retailing price.

(5) Determine the boundary value of whether the retailer's order quantity increases

If the retailer increases the order quantity in the two stages before and after the adoption of the cold chain technology, there is $q_G^* \ge q_N^*$, then $C_z \le [\gamma(e_1)/ \gamma(e_2)]^-$

$^{1/k}*\{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\varphi(e_1)\}*\varphi(e_2)-[\alpha_2(t)+\beta_2(t)+L]*\varphi(e_2)-[\alpha_1(t)+\beta_1(t)+C_0]$. Let C_z^q be the expression on the right side of the inequality. Since $0\leq\varphi(e_1)<\varphi(e_2)\leq1$, $0\leq\gamma(e_1)<\gamma(e_2)\leq1$, and $k>1$, $C_z^q>0$. Therefore, C_z^q is the decision boundary value of whether the retailers will increase the order quantity in the two stages before and after adopting the cold-chain technology.

If the retailer increases the order quantity in the two stages before and after the adoption of the cold chain technology, there is $q_G^* \geq q_N^*$, then $C_z\leq[\gamma(e_1)/\gamma(e_2)]^{-1/k}*\{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\varphi(e_1)\}*\varphi(e_2)-[\alpha_2(t)+\beta_2(t)+L]*\varphi(e_2)-[\alpha_1(t)+\beta_1(t)+C_0]$. Let C_z^q be the expression on the right side of the inequality. Since $0\leq\varphi(e_1)<\varphi(e_2)\leq1$, $0\leq\gamma(e_1)<\gamma(e_2)\leq1$, and $k>1$, $C_z^q>0$. Therefore, C_z^q is the decision boundary value of whether the retailer will increase the order quantity in the two stages before and after adopting the cold-chain technology.

Corollary 5: When technology adoption costs are lower, retailers increase order quantity. When the adoption cost is higher, the retailer reduces the order quantity to maintain a certain profit. When $0\leqslant C_z\leqslant C_z^q$, the retailer's order quantity for the product increases. When $C_z>C_z^q$, the retailer's order quantity for the product decreases.

$$C_z^q=[\gamma(e_1)/\gamma(e_2)]^{-1/k}*\{\alpha_2(t)+\beta_2(t)+L+[\alpha_1(t)+\beta_1(t)+C_0]/\phi(e_1)\}*\phi(e_2)-[\alpha_2(t)+\beta_2(t)+L]*\phi(e_2)-[\alpha_1(t)+\beta_1(t)+C_0] \quad (4\text{-}29)$$

4.3.4 The relationships of boundary values

Proposition 1: The relationship of boundary values $C_z^q<C_z^{sc}$, C_z^{sc} represents that when the cost of cold chain technology paid by wholesalers is increasing, and increases to the value of C_z^{sc}, the profit of the supply chain changes from greater profit when originally adopted to greater profit when not adopted. However, C_z^{sc} does not represent the overall cold chain technology cost of the supply chain.

Proof: If k> 1 is known, obviously $1/k<1/(k-1)$, and $0\leq\gamma(e_1)<\gamma(e_2)\leq1$, then there is $[\gamma(e_1)/\gamma(e_2)]^{-1/k}<[\gamma(e_1)/\gamma(e_2)]^{1/1-k}$. As evidenced by the expressions C_z^{sc} and C_z^{q} in Corollary 1 and Corollary 5, the formula can be infered: $C_z^{q} < C_z^{sc}$.

Proposition 2: Relationship of boundary value: $C_z^{w} < C_z^{q}$.

Proof: Knowing that $0\leq \gamma(e_1)< \gamma(e_2)\leq1$, then $\gamma(e_1)/\gamma(e_2)<1$, and if $k>1$, then $0<1/k<1$ and $[\gamma(e_1)/\gamma(e_2)]^{-1/k}>1$ can be gained, so C_z^{w} and C_z^{q} expressions in corollary 3 and corollary 5 prove that $C_z^{w} < C_z^{q}$.

Proposition 3: $C_z^{w} < C_z^{q} < C_z^{sc}$.

Proof: Combining Proposition 1 and Proposition 2, there is $C_z^{w} < C_z^{q} < C_z^{sc}$. Through the determination of the decision boundary value and its relationship, the following table (4-1) can be obtained.

Tab.4-1. The relationship between the adoption cost of cold chain and the wholesale and retail price, order quantity and profit of the circulation subject

	Value range of cold chain adoption cost			
	$0<C_z\leqslant C_z^{w}$	$C_z^{w}<C_z\leqslant C_z^{q}$	$C_z^{q}<C_z\leqslant C_z^{sc}$	$C_z>C_z^{sc}$
Wholesale Price	Reduce	Increase	Increase	Increase
Retail Price	Reduce	Increase	Increase	Increase
Order Quantity	Increase	Increase	Reduce	Reduce
Wholesaler Revenue	Increase	Increase	Increase	Reduce
Retailer Revenue	Increase	Increase	Increase	Reduce
Overall Supply Chain Revenue	Increase	Increase	Increase	Reduce

From Table 4-1, when the adoption cost of the cold chain is $0<C_z\leq C_z^{w}$, both wholesalers and retailers will reduce certain wholesale prices to obtain more orders and achieve the purpose of small profits but quick turnover; when technology adoption cost $C_z^{w}<C_z\leq C_z^{q}$, wholesalers will raise the wholesale price, transfer part of the adoption cost to retailers to bear, or refuse to adopt technology; And retailers

will also increase the wholesale price, part of the adoption cost transferring to consumers the responsibility, or refuse to adopt technology.

When the adoption cost of cold chain is $0 < C_z \leq C_Z^q$, the retailer will increase the order quantity to achieve the purpose of small profits but quick turnover; When the adoption cost is $C_z > C_Z^q$, the retailer reduces the order quantity to maintain a certain profit.

When the adoption cost of the cold chain is $0 < C_z \leq C_Z^{sc}$, the revenue of both wholesalers and retailers increases, and the overall revenue of the supply chain increases; When $C_z > C_Z^{sc}$, the revenue of both wholesalers and retailers decreases, and the supply chain total return also decreased.

5 Analysis of example

Taking litchi as an example, a reference example and actual situation are used to analyze examples to verify the validity of the model established in this paper and the propositions obtained.

Assuming that the cost of litchi products is $C_0=1.5$ yuan / kg, the market demand elasticity is $k=2$, and the demand scale A is 700,000; from the selection and value of the quality experiment indicators in Chapter 3 of this thesis, the preservation ratio of litchi products under normal temperature conditions It is $\Phi(e_1)=0.72$, product quality function $\gamma(e_1)=0.80$, wholesaler logistics transportation cost $\alpha_1(t)=2.2$ yuan / kg, retailer logistics transportation cost $\alpha_2(t)=1.2$ yuan / kg. The logistics storage cost of wholesalers is $\beta_1(t_1)=0.9$ yuan / kg, the logistics storage cost of retailers $\beta_2(t)=1.5$ yuan / kg, the processing and packaging of litchi products by retailers, the cost is $L=0.3$ yuan / kg.

From the experimental analysis of litchi quality in Chapter 3 of this article, the quality of litchi is very sensitive to temperature changing is known, and the preservation ratio and quality of litchi products can be improved by using cold chain technology. After adopting the cold chain technology, the product preservation ratio of litchi is $\phi(e_2)$=0. 92, and product quality function is $\gamma(e_2)$=0. 93, as well as the logistics transportation cost of wholesalers is $\alpha_1(t)$= 2. 2 yuan / kg, and the logistics transportation cost of retailers $\alpha_2(t)$=1. 2 yuan / kg. The logistics warehousing cost of wholesalers is $\beta_1(t)$=0. 9 yuan / kg, the logistics warehousing cost of retailers is $\beta_2(t)$=1. 5 yuan / kg, the adoption cost of cold chain technology is C_z=0. 9 yuan / kg. The model has the following table 5-1 Changes in supply chain decision parameters:

Tab.5-1. Changes in supply chain decision parameters before and after cold chain technology adoption

Wholesale Price	Retail Price	Retailer Order Quantity	Wholesaler Revenue	Retailer Revenue	Total Supply Chain Revenue
$\boldsymbol{w_N^*}$=15.78	p_N^*=37.56	$q_N^{*\ B}$=397.04	π_N^{m*}=3727.81	π_N^{r*}=7455.62	π_N^{sc*}=11183.43
$\boldsymbol{w_G^*}$=14.96	p_G^*=35.91	q_G^*=504.75	π_G^{m*}=4531.78	π_G^{r*}=9063.56	π_G^{sc*}=13595.34

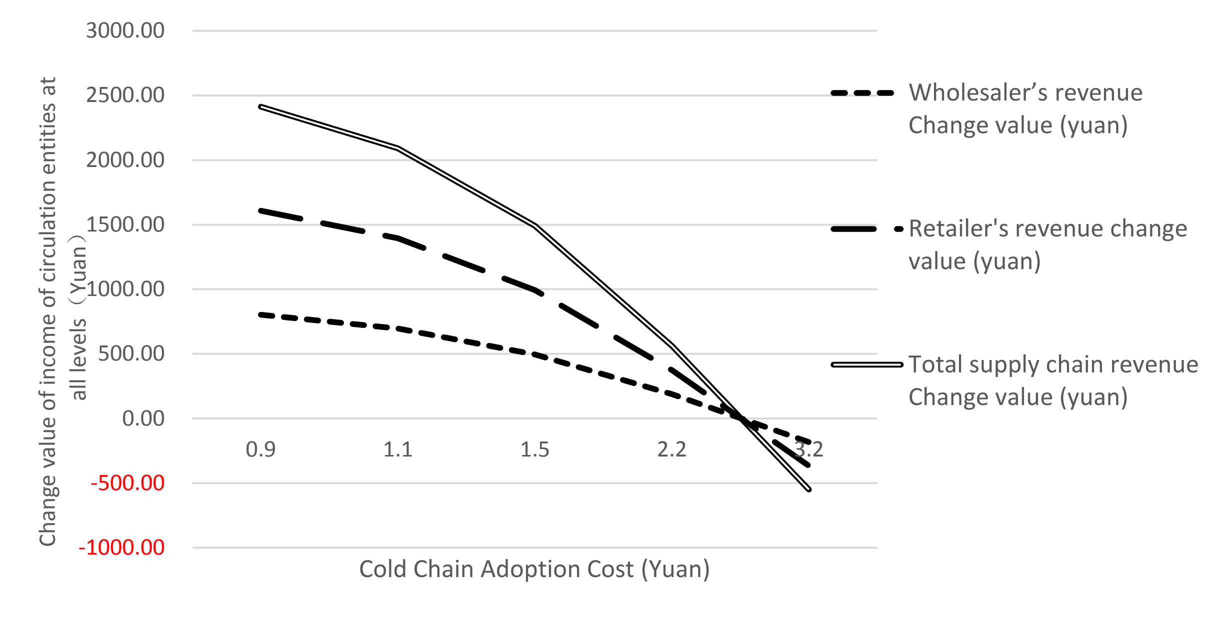
5.1 Impact of Cold Chain Adoption Cost on Adoption Decision Parameters

It is known from Table 5-1 that when the cold chain adoption cost C_z =0. 90, the wholesale price on the litchi supply chain decreased by 5%, the retail price decreased by 4%, and the order quantity increased by 27%. Wholesalers, retailers and the supply chain as a whole income of the company increased by 22%. According to the theoretical model in Chapter 4 of this paper, it can be deduced that the important boundary values that affect the decision and decision parameters of litchi cold chain logistics areC_z^w =1. 28, C_z^q=1. 95, C_z^{sc}=2. 68, which is consistent with the boundary value proposition Relationship: $C_z^w < C_z^q < C_z^{sc}$. Obviously, when the adoption cost C_z =0. 90, it exists in the interval [0, 1.28], that is, in $[0,\ C_z^w]$, the corresponding parameters The changes worthwhile are in line with the conclusion in table 4-1. Based on the calculated three decision boundary values, the changes in supply chain wholesale price, retail price, order quantity, the income of the circulation entities at all levels and the overall income value under different cold chain technology adoption costs can be analyzed, see table 5-2. It is consistent with the conclusion of the theoretical model in Table 4-1, which verifies the validity and accuracy of the model.

Tab. 5-2. Comparison of different cold chain adoption costs compared with the adoption of cold chain technology

Range and Value of C_z		Wholesale prices Change value (yuan)	retail price Change value (yuan)	Order value change (kg)	Wholesaler's revenue Change value (yuan)	Retailer's revenue change value (yuan)	Total supply chain revenue Change value (yuan)
$0 < C_z \leqslant C_z^w$	0.9	-5.21%	-4.37%	27.13%	21.57%	21.57%	21.57%
$0 < C_z \leqslant C_z^w$	1.1	-2.45%	-2.06%	21.19%	18.69%	18.69%	18.69%
$C_z^w < C_z \leqslant C_z^q$	1.5	3.06%	2.57%	10.49%	13.33%	13.33%	13.33%
$C_z^q < C_z \leqslant C_z^{sc}$	2.2	12.71%	10.68%	-5.10%	5.04%	5.04%	5.04%
$C_z > C_z^{sc}$	3.2	26.48%	22.25%	-22.22%	-4.91%	-4.91%	-4.91%

5.2 The Impact of Cold Chain Adoption Cost on the Revenue of Litchis' Circulation Subjects at All Levels



Picture 5-1: Trend chart of revenue changes of litchi circulation entities before and after cold chain adoption

In order to further verify the effectiveness of the model constructed in this thesis, assuming other parameters remain unchanged, changing the cold chain adoption cost C_z, Figure 5-1 can be obtained: the vertical axis represents the value of the profit change of the litchi circulation agents at all levels, and the horizontal axis is cold Chain technology adoption costs. It can be seen from the figure that when the cold chain adopts the cost $C_z < C_z^{sc}$, the income of the cold chain logistics circulation entities at all levels increases, the overall supply chain income also increases, and the change in income is positive, as well as the added value of the retailer's income is greater than that of the wholesale added value of the quotient's income. As the cost of technology increases, the value of the main body's revenue at all levels and the increase in the overall revenue of the supply chain both show a decreasing trend until the cost of $C_z > C_z^{sc}$ is adopted, and the value of the change in income all becomes negative. The subject will give up adopting cold chain technology. The overall change is consistent with the theoretical model.

5.3 Impact of Cold Chain Adoption Cost on Wholesale and Retail Prices and Order Quantity

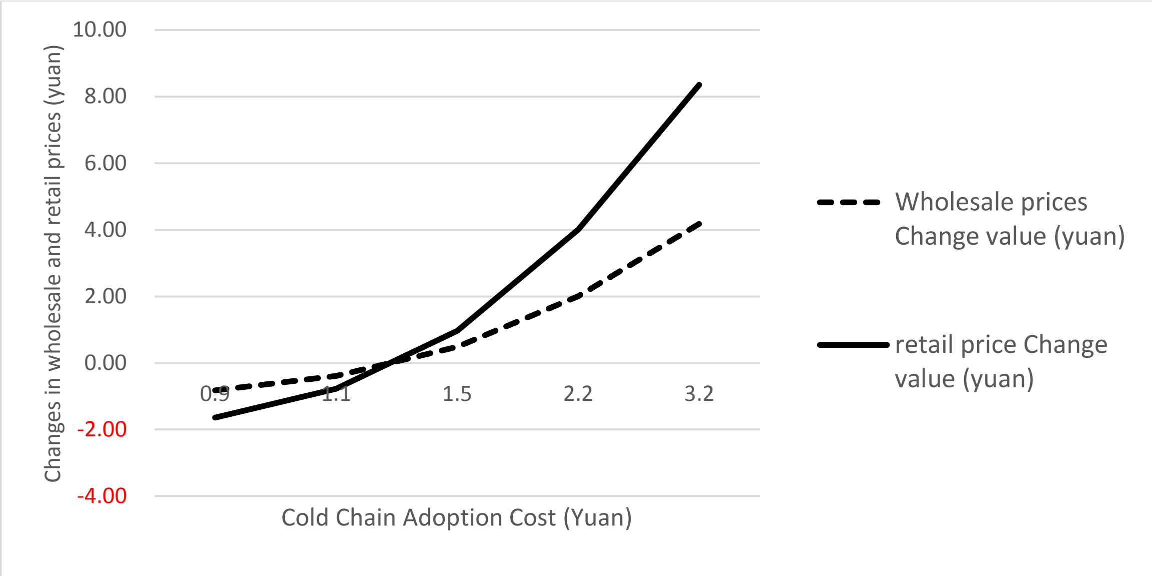


Figure 5-2: Trend chart of wholesale and retail prices before and after cold chain adoption

From Figure 5-2, the changes in the wholesale and retail prices of litchi before and after the adoption of cold chain technology can be gained. When the cold chain technology cost C_z<C_z^w, the wholesale and retail price changes are negative, indicating There are price reductions, which are lower than the prices before the adoption of cold chain technology. When the cost of cold chain C_z>C_z^w, the changes in wholesale and retail prices are positive, which are both higher than those before cold chain technology. As can be seen from Figure 5-2, the increase in retail prices is greater than the increase in wholesale prices. The overall change is consistent with the theoretical model.

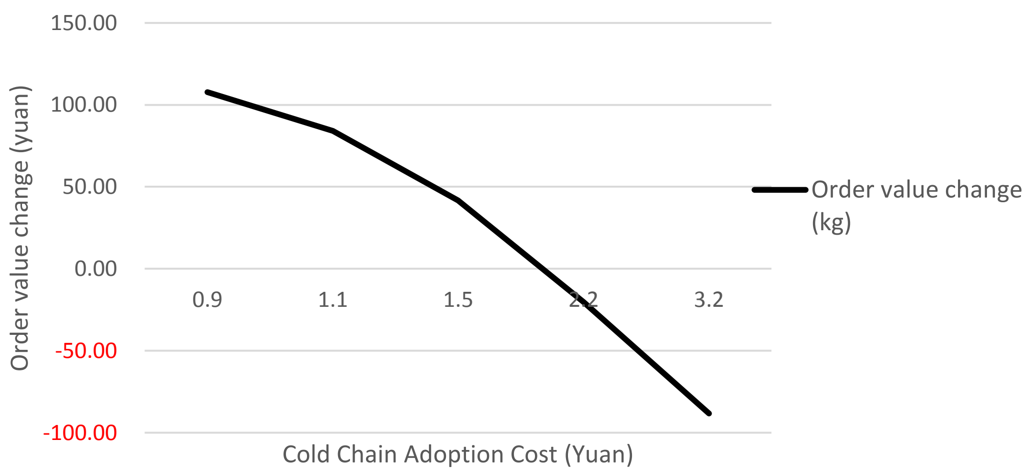


Figure 5-3 Change trend of order quantity before and after cold chain adoption

Figure 5-3 shows the change in the order quantity with the increase in the cold chain adoption cost. It shows that when the adoption cost C_z<C_z^q, the retailer's order quantity is larger than the order quantity before the cold chain technology was adopted, and the quantity decreases as the cost of technology increases. When the adoption cost C_z<C_z^q, the change in the order quantity is negative, and the order quantity is less than the order quantity before adopting the cold chain technology. The overall change is consistent with the theoretical model.

6 Conclusion

The application of cold chain has significantly improved the quality of fresh lychee logistics, but at the same time increased operating costs. Therefore, it is more scientific to make the decision to adopt cold chain by analyzing the cost and benefit of circulation entities at all levels. This article first conducts quality experiments on litchi to analyze the changes in litchi logistics quality under three different logistics conditions: room temperature, cold chain, and partial cold chain; and then compares the costs of the upstream and downstream of the litchi supply chain in the two stages before and after the cold chain adoption. With regard to income, it focuses on analyzing the impact of cold chain adoption on litchi quality, wholesale price, retail price, order quantity, and income of all levels of circulation entities, and derives four boundary values closely related to litchi supply chain income, and then finds: wholesale Prices, retail prices, and order quantities are all affected by transportation costs, warehousing costs, cold chain adoption costs, product quality, and preservation ratios. Among them, order quantities are also affected by market price elasticity coefficients.

When the cost of cold chain technology adoption is within a certain range, the wholesale price and retail price will fall, the order quantity will increase, and the revenue of all levels of circulation entities will increase. After adopting cold chain technology, wholesalers, retailers, and the overall profit decision boundary value of the supply chain are the same. The increased revenue value of the retailer is greater than that of the wholesaler, and the retail price changes more than the wholesale price.

Finally, an example is used to verify the correctness of the model and the results: When the cold chain adoption cost Cv*=0.90 yuan/kg, the wholesale price in the litchi supply chain will drop by 6%, the retail price will drop by 4%, and the order quantity will increase by 27%. The revenue of wholesalers, retailers and the overall supply chain all increased by 22%. When the cost of adoption continued to increase to 3.2 yuan/kg, the wholesale price in the litchi supply chain rose by 26%, the retail price rose by 22%, and the order quantity decreased by 22%, The revenue of wholesalers, retailers and the supply chain as a whole fell by 5%, and the parameter changes are consistent with the theoretical model constructed in this paper. This thesis provides a scientific basis for lychee operating companies to invest in the cold chain.

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